Chapter 4
Detailed Inspection

4-1. Introduction

This chapter summarizes appropriate inspection procedures, nondestructive testing (NDT) inspection methods, required inspector qualifications, and code acceptance criteria for defects in new weldments.

4-2. Purpose of Inspection

a. If distressed structural members or connections are identified in the periodic inspection or deterioration in structural performance is assessed from the initial evaluation, then the entire structure should receive a more detailed inspection. Detailed inspections may also be used as part of a damage-tolerance fracture control plan. This fracture control concept is based on the fact that presence of cracklike discontinuities in the structural members or connections does not necessarily mean the end of the service life of the structure. An integrated approach using scheduled inspections on the flawed members and analysis of fracture/fatigue resistance of the same members can assure satisfactory structural performance. The cost for repair or replacement of the flawed members can therefore be balanced against the inspection cost.

b. To develop schedules for inspection when the damage-tolerance fracture control plan is used, fracture mechanics theories must be applied. The inspection periods can be determined by fatigue propagation analysis of the cracked structural members. The crack growth history from a detectable size to the critical size can be predicted using the propagation laws (e.g., Paris's crack growth law). Time interval between inspections should be a fraction of this crack growth life. The optimum inspection intervals vary with service conditions and the discontinuity conditions. These inspection intervals should be short enough that the cracks that were not detectable at the preceding inspections do not have time to propagate to failure before the next scheduled inspection. A procedure for planning the inspection schedules from the crack growth analysis is presented in Chapter 6.

4-3. Inspection Procedures

a. Inspection of cracks. Field inspection for cracking on welded or riveted structures can be accomplished by various NDT methods. The six NDT methods commonly used in industry are visual testing (VT), penetrant testing (PT), magnetic-particle testing (MT), radiographic testing (RT), ultrasonic testing (UT), and eddy-current testing (ET). Selection of an NDT method for inspection depends on a number of variables, including the nature of the discontinuity, accessibility, joint type and geometry, material type, detectability and reliability of the inspection method, inspector qualifications, and economic considerations. A summary of NDT methods that describes advantages and disadvantages of each is provided in paragraph 4-5 and Table 4-1. The following are recommended steps for inspecting for cracks:

(1) Visual examination, particularly with the aid of a magnifying glass (5 $\times$ or higher), is the most efficient first step.

(2) If cracks are suspected and the gate component is dry, PT inspection can be used to confirm the presence of a crack. For most cases, more sophisticated methods, such as UT and MT, can also be employed but may not be needed.

(3) Record the location, orientation, and length of the cracks. Record conditions of the gate when cracks are detected.

Table 4-1
Selection Guide for Inspection Method

Method	Applications	Advantages	Disadvantages
Visual	Surface discontinuities	Economical, fast	Limited to visual acuity of the inspector
Liquid penetrant	Surface cracks and porosity	Relatively inexpensive and reasonably rapid	Cleaning is needed before and after inspection. Surface films hide defects
Magnetic particle	Surface discontinuities and large subsurface voids	Relatively economical and expedient	Applicable only to ferromagnetic materials
Radiographic	Voluminous discontinuities Surface and internal discontinuities	Provides a permanent record	Planar discontinuities must be favorably aligned with radiation beam. Cost of equipment is high
Ultrasonic	Most discontinuities	Sensitive to planar type discontinuities. High penetration capability	Small, thick parts may be difficult to inspect. Requires a skilled operator.
Eddy current discontinuities	Surface and subsurface can be inspected.	Painted or coated surfaces signal High speed	Many variables can affect the test

(4) Take photographs of all cracks showing their position relative to the components of the structure.

(5) The inspector should complete a report following the actual inspection. The report should include the identification and location of inspected structures, date and time of inspection, type of inspection, inspection procedure, inspection equipment, inspector identity and qualifications, and a record of discontinuities detected that includes the location, size, orientation, and classification of each discontinuity. Standard symbols are found in AWS (1998b).

b. Inspection for loose rivets. The inspection of riveted structures should include procedures to identify loose and/or deteriorated rivets. Loose rivets may exist where there are corrosion patterns around the rivet head (as shown in Figure 4-1) or where fretting corrosion (Chapter 2) is observed. A rivet with a deteriorated head may be loose. If loose rivets are suspected, a nonvisual means of inspection is likely required. A commonly practiced nonvisual inspection technique is to impact the rivet head transversely with a hammer. The effectiveness of the rivet may be judged by the tone of the impact. Ewins (1985) describes a method in which the rivet is impacted longitudinally with an instrumented impact hammer. A vibration signal is emitted from the tested rivet. By monitoring the vibration signal emanating from the rivet and comparing the signal to that of a sound rivet, the condition can be determined. The magnitude of the impact force must be consistent for these comparisons. Generally, the signal from a loose rivet will have a lower and broader frequency than the signal from a sound rivet. During inspection, it is not necessary to check each rivet in a structure. Detrimental situations can be identified by testing a representative sample of rivets.

c. Inspection for corrosion. Appropriate tools to assist in measuring and defining corrosion damage include a depth micrometer (for pitting), feeler gages (for crevice corrosion), an ultrasonic thickness gage (for thinning), a ball peen or instrumented hammer (for corroded or loose rivets), a camera, a tape measure, and a means to collect water samples. When corrosion is observed, the type, extent, severity, and possible cause should be reported. If the corrosion is severe, the specific locations should be noted and the severity (amount of thinning, etc.) should be quantitatively determined. Some guidelines on subjective quantification of the severity of corrosion damage are given by Greimann, Stecker, and Rens (1990). If extensive paint system failure is evident, the river water should be analyzed for corrosiveness. Weight loss (ASTM D2688) and electrochemical (ASTM G96) methods can be used to determine the corrosivity of water. Corrosivity of water can also be determined by correlation with pH and ion concentration levels (Pisigan and Singley 1985).

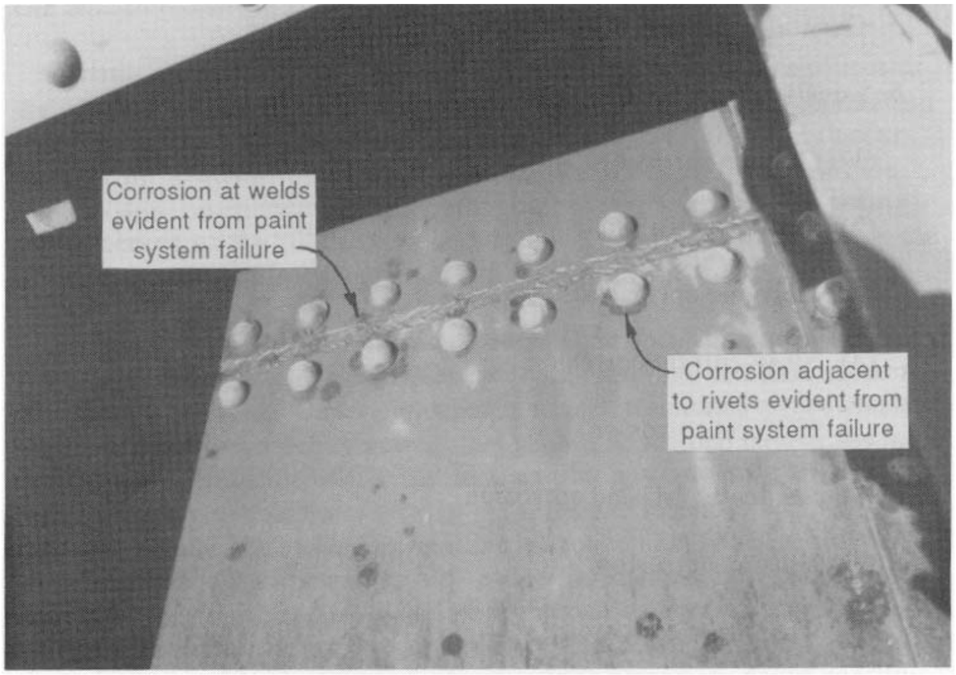

Figure 4-1. Localized corrosion

Although each of these techniques can be used, the weight loss and electrochemical methods are recommended since they provide a more direct measurement and are easier to apply. Common NDT methods that can be applied for inspecting structures for corrosion damage include VT inspection and UT inspection. Newer methods of inspecting for corrosion, such as magnetic resonance testing, are being developed, but these are not yet ready for routine implementation.

(1) Visual inspection.

(a) Visual inspection is the primary NDT technique of inspecting for corrosion. It can be done in situ, usually with only ordinary lighting. A visual inspection of all corrosion-susceptible areas (identified in Chapter 2) should be made to locate, identify, and determine the extent of corrosion. Any failure of the paint system should also be identified.

(b) The extent of corrosion at crevice sites, particularly in riveted structures, should be recorded during each inspection. A sheet feeler gauge may be used to quantify the width of a crevice exhibiting corrosion. Measuring the depth of the crevice (distance into the crevice) may be difficult due to corrosion product blocking the gauge.

(c) When corrosion exists around rivet heads, deterioration of the rivet head and rivet should be checked. A deteriorated rivet will have reduced strength and may not perform as intended. Figure 4-2 shows where rivet heads have split or have developed rosette heads. A corrosion pattern around a rivet may suggest that corrosion is occurring somewhere beneath the rivet head, or that the rivet is loose. Figure 4-1 shows such a corrosion pattern. The corrosion pattern should always be recorded in these instances.

(d) The extent of paint system failure and regions of localized discoloration of structural components should be recorded. In areas where paint failure has occurred, the surface should be visually examined for pitting. When pitting is present, it should be quantified using a probe type depth gauge following guidance specified in ASTM G46.

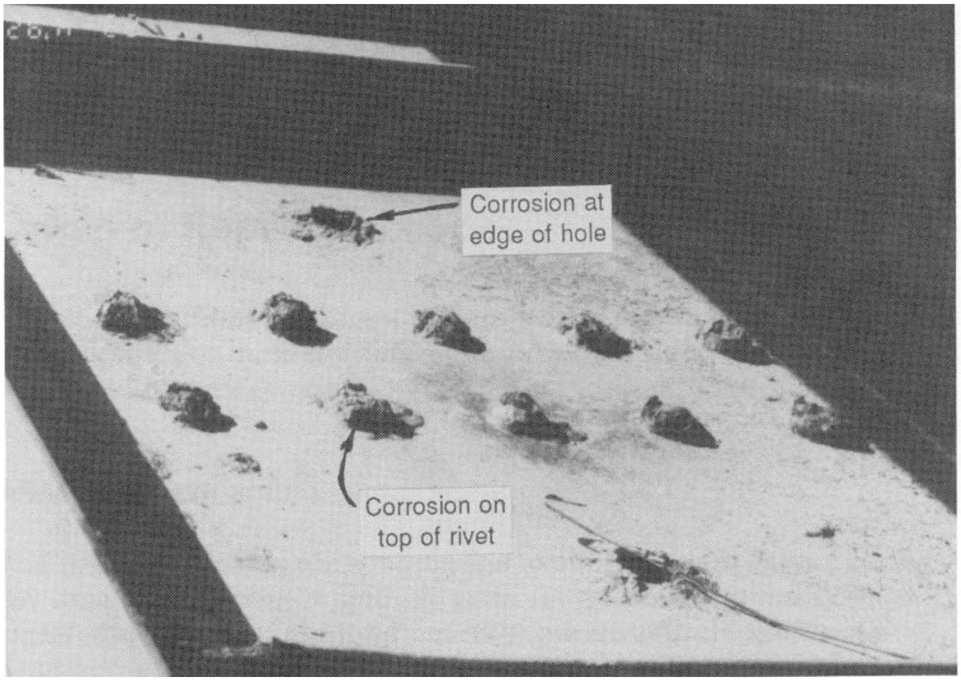

Figure 4-2. Corrosion of rivet heads

(2) Ultrasonic inspection.

(a) Ultrasonic inspection is useful when corrosion appears to have caused significant thickness loss in critical components and can be used to obtain a baseline reference for thickness. The thickness of a steel plate or part can be determined to an accuracy of ±0.01 cm (0.005 in.). The technique can be performed through a paint film or through surface corrosion with only a slight loss in accuracy. Ultrasonic transducers are available in a number of sizes. Thus, ultrasonic inspection is useful in determining both general and localized thickness loss due to corrosion, even on curved skin plates.

(b) Ultrasonic inspection can be used when only one side of a component is accessible. The open surface can be scanned with the transducer to identify thickness variation over the surface and to determine where corrosion has occurred. Methods and equipment for automated scanning and mapping of thickness variation are available but are probably not economically justifiable for in situ use on hydraulic steel structures.

(c) When ultrasonic inspection is used, the transducer must be coupled to the steel using a coupling liquid, but this is not a serious limitation. Ultrasonic inspection to determine thickness is generally not reliable when pitting corrosion is prevalent, because the size and depth of the pitting impair the output signal of the transducer.

d. Inspection for plastically deformed members. When plastically deformed or buckled members are found during an inspection, the type and extent of the deformation must be described accurately and in detail so that an assessment of the effect of the damage can be made. The location of the damaged member should be noted as well as the type and extent of deformation (global member buckling, local buckling of a flange, or impact damage to the skin plate). The magnitude of all deformations should be measured and recorded. Sketches and photographs should be made. The condition of adjacent members, effect on structure performance or operation, and possible causes of the damage should also be noted.

4-4. Inspector Qualifications

For the results of an inspection to be worthwhile, the inspector must be qualified. Corps personnel are often not adequately trained in inspection methods; therefore, inspections are often performed via contract with inspection specialists. The following qualification requirements apply to all inspectors, whether Government or contractor employees.

a. Qualification in NDT methods.

(1) The effectiveness of NDT depends on the capabilities of the person who performs the test. Inspectors performing NDT should be qualified in accordance with the American Society for Nondestructive Testing (ASNT) Recommended Practice No. SNT-TC-1A (ASNT 1980). The SNT-TC-1A document is a guide to establish practices for training, qualification, and certification of NDT personnel. Three basic levels of qualification are defined in SNT-TC-1A as follows:

(a) NDT Level I: An NDT Level I individual shall be qualified to properly perform specific calibrations, specific NDT, and specific evaluations for acceptance or rejection determinations according to written instructions and to record results.

(b) NDT Level II: An NDT Level II individual shall be qualified to set up and calibrate equipment and to interpret and evaluate results with respect to applicable codes, standards, and specifications. The NDT Level II individual shall be able to organize and report the results of NDT.

(c) NDT Level III: An NDT Level III individual shall be capable of establishing techniques and procedures; interpreting codes, standards, and procedures; and designating the particular NDT methods, techniques, and procedures to be used.

(2) Certification of all levels of NDT personnel is the responsibility of the employer. The employer must establish a written practice for the control and administration of NDT personnel training, examination, and certification.

b. Qualification in weld inspection.

(1) Welding inspectors are responsible for judging the quality of the product in relation to some form of written specification. The following qualifications are necessary for individuals to inspect welds adequately.

(a) A welding inspector must be familiar with engineering drawings and able to interpret specifications.

(b) A welding inspector should be familiar with welding processes and welding procedures.

(c) A welding inspector should be able to maintain adequate records.

(d) A welding inspector should have passed an eye examination with or without corrective lenses to prove near-vision acuity of Snellen English, or equivalent, at 300 mm (12 in.), and far-vision acuity of 20/40, or better.

(2) In addition, one of the following three requirements is necessary to qualify an individual as a weld inspector for a hydraulic steel structure:

(a) Current or previous certification as an AWS Certified Welding Inspector (CWI) in accordance with the provisions of ANSI/AWS QC1.

(b) Current or previous qualification by the Canadian Welding Bureau (CWB) to the requirements of the Canadian Standard Association (CSA) Standard W178.2 (CSA 1917).

(c) An engineer or technician who, by training, experience, or both, in metals fabrication, inspection, and testing, is competent to perform inspection of the work.

4-5. Summary of NDT Methods

a. Detailed visual testing (VT). Detailed VT inspection uses the same inspection tools and procedure as normal VT (described in Chapter 3), except that because existing discontinuities in a structural member or connection are known from periodic inspections, a more concentrated examination is performed. The type, geometry, size, location, and orientation of the discontinuities must be quantitatively determined. The entire structure may be inspected rather than just representative members or connections. VT inspection is described in ANSI/AWS B1.10.

(1) Advantages. VT inspection is useful for checking the presence of surface discontinuities. It is simple, quick, and easy to apply. It requires no special equipment other than good eyesight, sometimes assisted by simple and inexpensive equipment.

(2) Disadvantages and limitations. A major disadvantage of VT inspection is the need for an inspector who has considerable experience and knowledge in many different areas. Although VT inspection is an invaluable method for detecting surface discontinuities, it is less reliable in detecting and quantifying small surface discontinuities or detecting subsurface discontinuities.

b. Penetrant testing (PT). PT inspection is also a method used to detect and locate surface discontinuities. PT is described by ASTM E165 and E1316, and ANSI/AWS B1.10. Liquid penetrants can seep into various types of minute surface openings by capillary action. Therefore, this process is well suited for detecting discontinuities such as surface cracks, overlaps, porosity, and laminations. PT inspection can be performed using visible dye or fluorescent dye visible with ultraviolet light. Three different penetrants commonly used with either dye are water washable, solvent removable, and postemulsifiable. The various penetrant inspection systems are listed in order of decreasing inspection sensitivity and operational cost as follows:

- Postemulsifiable fluorescent dye
- Solvent-removable fluorescent dye
- Water-washable fluorescent dye
- Postemulsifiable visible dye
- Solvent-removable visible dye
- Water-washable visible dye

(1) Advantages. PT inspection is relatively inexpensive and reasonably rapid. Equipment generally is simpler and less costly than that for most other NDT methods.

(2) Disadvantages and limitations. The major limitation of PT inspection is that it can detect only discontinuities that are open to the surface. Another disadvantage is that the surface roughness of the object being inspected may affect the PT inspection results. Extremely rough or porous surfaces may produce false

indications. Some substances in the penetrants can affect structural materials. If penetrants are corrosive to the material being inspected, they should be avoided.

c. Magnetic particle testing (MT). MT inspection is used to detect surface or near-surface discontinuities in ferromagnetic materials. ASTM E709 and E1316 and ANSI/AWS B1.10 provide information on MT. Magnetic fields can be generated by yokes, coils, central conductors, prod contacts, and induced current. When the material is magnetized, magnetic discontinuities that lie in a direction generally transverse to the direction of the magnetic field will cause a leakage field at the surface of the material. The presence of this leakage field is detected when fine ferromagnetic particles are applied over the surface. Some of the particles are gathered and held by the leakage field. This collection of particles indicates the discontinuities. Several magnetic particle materials commonly used for MT inspection are dry powders (i.e., suitable for field inspection of large object), wet magnetic particles suspended in water or light oil (i.e., suitable for very fine or shallow discontinuities), magnetic slurry suspended in heavy oil, and magnetic particles dispersed in the liquid polymers to form solid indications.

(1) Advantages. The MT inspection is a sensitive means of detecting small and shallow surface or near-surface discontinuities in ferromagnetic materials. MT inspection is considerably less expensive than radiographic or ultrasonic inspection and is generally faster and more economical than penetrant inspection. Compared to PT inspection, MT inspection has the advantage of revealing cracks filled with foreign material.

(2) Disadvantages and limitations. MT inspection is limited to ferromagnetic material. For good results, the magnetic field must be in a direction that will intercept the direction of the discontinuity. Large currents sometimes are required for very large parts. Care is necessary to avoid local heating and burning of surfaces at the points of electrical contact. Demagnetization is sometimes necessary after inspection. Discontinuities must be open to the surface or must be in the near subsurface to create flux leakage of sufficient strength to accumulate magnetic particles. If a discontinuity is oriented parallel to the lines of force, it will be essentially undetectable.

d. Radiographic testing (RT). RT inspection is based on differential absorption of penetrating radiation by the material being inspected. Radiation from the source is absorbed by the test piece as the radiation passes through it. The discontinuity and its surrounding material absorb different amounts of penetrating radiation. Thus, the amount of radiation that impinges on the film in the area beneath the discontinuity is different from the amount that impinges in the adjacent area. This produces a latent image on the film. When the film is developed, the discontinuity can be seen as a shadow of different photographic density from that of the image of the surrounding material. Evaluation of the radiograph is based on a comparison of these differences in photographic density. The dark regions represent the more easily penetrated parts (i.e., thin sections and most types of discontinuities) while the lighter regions represent the more difficult areas to penetrate (i.e., thick sections). An essential element to the radiographic process is film, a thin transparent plastic base coated with fine crystals of silver bromide (emulsion). RT inspection shall conform to ASTM E94, ASTM E142, ASTM E747, and ASTM E1032. Other applicable documents include ASTM E242, ASTM E1316, ASTM E999, ASTM E1025, ANSI/AWS B1.10, and ANSI/AWS D1.1.

(1) Advantages. RT inspection detects surface and internal discontinuities, is generally not restricted by the type of material or grain structure, and provides a permanent record for future review.

(2) Disadvantages and limitations. RT presents a potential radiation hazard to personnel, is costly (radiographic equipment, facilities, and safety programs are expensive), and is relatively time consuming. The RT method is difficult to conduct during field applications. To provide reliable detection, discontinuities must be favorably aligned with the radiation beam, and accessibility to both sides of the parts to be inspected is required.

e. Ultrasonic testing (UT). UT inspection is a nondestructive method in which high-frequency sound waves are used to detect surface and internal discontinuities. The sound waves travel through the materials to be inspected and are reflected from surfaces, refracted at interfaces between two substances, and diffracted at edges or around obstacles. The reflected sound waves are detected and analyzed to define the presence and location of discontinuities. Cracks, laminations, shrinkage cavities, pores, and other discontinuities that act as metal-gas interfaces can be easily detected. Inclusions and other nonhomogeneous defects in the metal can also be detected. UT inspection is usually performed with longitudinal waves or shear waves (i.e., angle beam). Most UT inspections for discontinuities are performed using angle-beam technique. The pulse-echo method with A-scan is most commonly used for inspection of welds. The most commonly used frequencies are between 1 and 5 MHz, with sound beams at angles of 0, 45, 60, and 70 degrees. During application of the method, all surfaces of the part to be examined should be free of weld spatter, dirt, grease, oil, paint, and loose scale. Applicable guidance documents include ASTM A435/A435M, ASTM A577/A577M, ASTM E114, ASTM E164, ASTM E214, ASTM E1316, ANSI/AWS B1.10, and ANSI/AWS D1.1.

(1) Advantages. UT provides near-instantaneous indications of discontinuities. It is not hazardous to personnel, nor does it have adverse effects on materials. The method is very accurate. It has superior penetrating power allowing the detection of discontinuities deep in the part, is highly sensitive permitting the detection of small discontinuities, and provides good accuracy in determining the size, position, and shape of discontinuities.

(2) Disadvantages and limitations. Manual operation and interpretation of results require experienced technicians. Even with experienced personnel, reference standards are needed for calibrating the equipment and for characterizing discontinuities. Parts that are rough, irregular in shape, very small, or inhomogeneous are difficult or impossible to inspect.

f. Eddy-current testing (ET). ET inspection is an electromagnetic method that is based on the principles of electromagnetic induction. When an alternating current is passed through a coil, eddy current is created in the material being tested by an alternating magnetic field. The test coil is electronically monitored to detect the changes of magnetic field caused by the interaction between the eddy currents and the initial field. Any surface or subsurface discontinuities that appreciably alter the normal flow of eddy currents can be detected by ET inspection. ASTM E1316 and ANSI/AWS B1.10 provide guidance on the use of ET.

(1) Advantages. Because ET inspection is an electromagnetic induction technique, it does not require direct contact between probe and the material being tested, so coated materials can be inspected. ET inspection is adaptable to high-speed inspection.

(2) Disadvantages and limitations. The test material must be an electrical conductor (not a concern for inspection of hydraulic steel structures). Internal discontinuities that are more than approximately 6 mm (1/4 in.) from the surface cannot be accurately detected by eddy-current inspection. The method is based on indirect measurement, and the correlation between the instrument readings and the structural characteristics of the material being inspected must be carefully established. Since many variables can affect an eddy-current signal, interpretation of results must be done by experienced personnel.

4-6. Discontinuity Acceptance Criteria for Weldments

a. Discontinuity classification. The common weld discontinuities detected from various NDT methods can be classified into planar and nonplanar types. Planar type discontinuities include cracks, delaminations or laminar tearing, and sometimes incomplete joint penetration or incomplete fusion. The nonplanar type discontinuities are volumetric weld discontinuities, which include porosity, slag or tungsten inclusions, undercut, underfill, and overlap. Figure 4-3 shows these common types of weld discontinuities (ANSI/AWS B1.10).

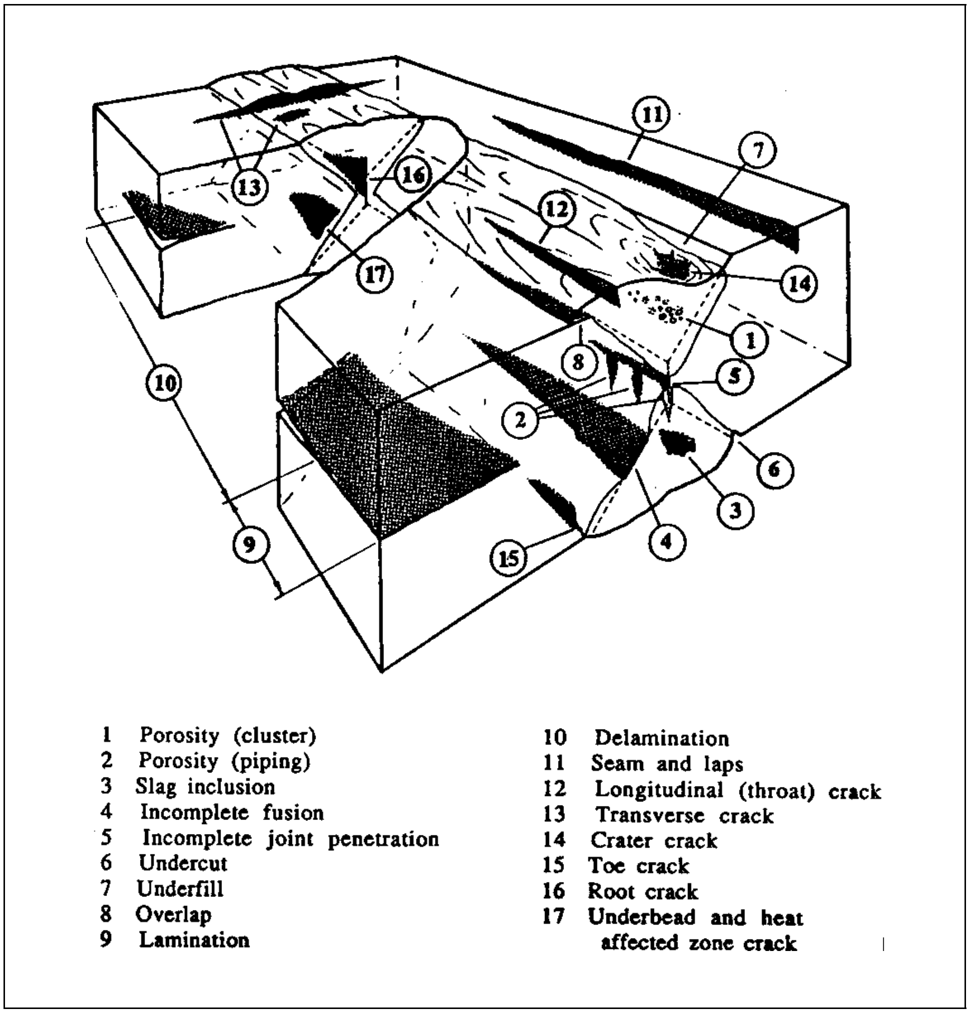

Figure 4-3. Weld discontinuities (ANSI/AWS B1.10; copyright permission granted by American Welding Society)

b. Acceptance criteria. The results obtained from various NDT inspections for new fabrication are assessed according to the recommended acceptance criteria for weld discontinuities as presented by ANSI/AWS D1.1. These acceptance criteria as they apply to various NDT inspection results can be summarized in three perspectives: weld profile, static loading case, and dynamic loading case. Weld profile is a code compliance for weld quality. Inspection for this code compliance is usually made by visual inspection with the aid of a weld gauge. The purpose of this code compliance is to provide information on the structural fitness of the welds. Weld profile noncompliance may be acceptable if an engineering assessment is conducted. The code acceptance criteria recognize the effect of dynamic loading on the structures as opposed to the statically loaded case. Planar type discontinuities are not acceptable in either case, and permissible conditions on nonplanar type discontinuities are specified in the code criteria with smaller allowances for the dynamically loaded structures. Repair or replacement of structural members or connections that contain unacceptable discontinuities (i.e., flaws) may be required. These acceptance criteria are obviously applicable to existing structures with discontinuities as well. To avoid unnecessary repair or replacement, fracture mechanics analysis may be conducted to reassess these unacceptable discontinuities for new fabrication or existing structural weldments. A maintenance schedule may be developed in lieu of immediate repair or replacement of the distressed members or connections using a damage-tolerance fracture control plan (Chapter 6).